

# SUSY & 3rd Generation Squarks

Searches & Results from ATLAS

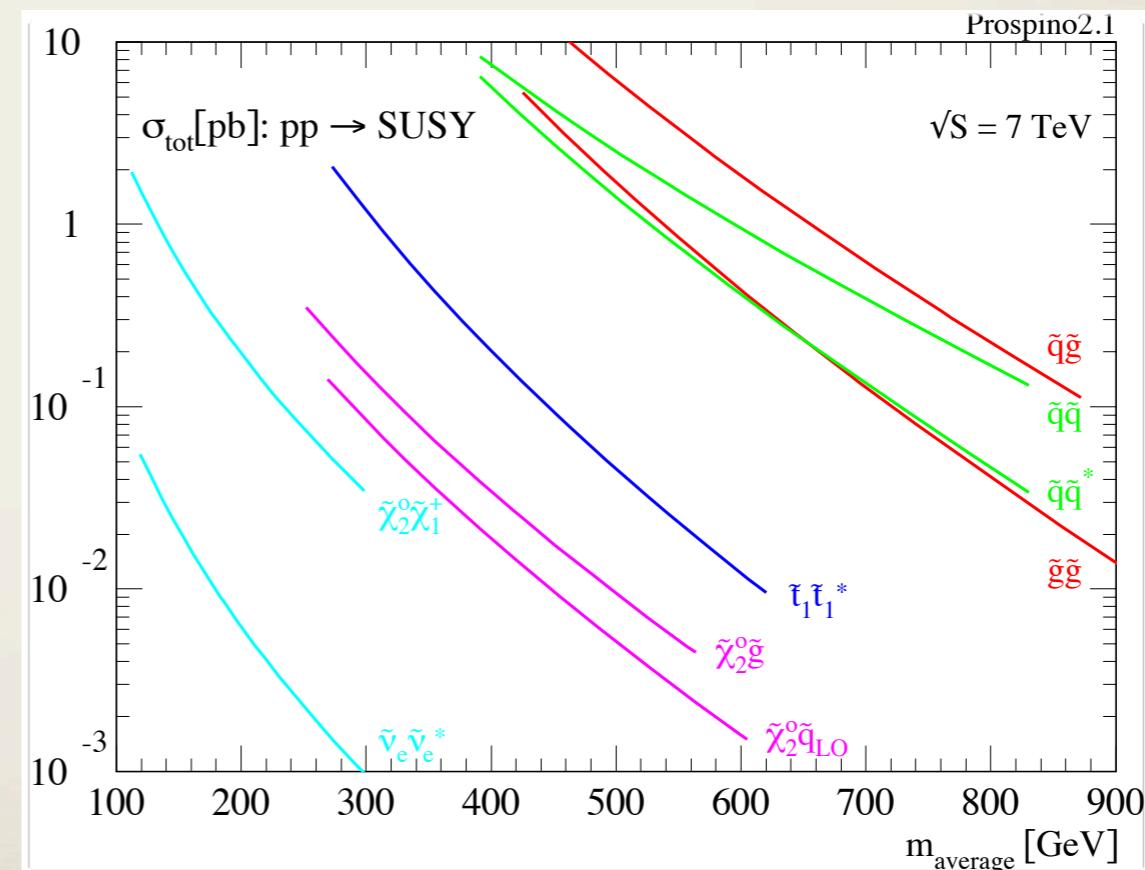
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Physics 290E Seminar ~ November 16, 2011



# Introduction

- Assuming R-parity conservation, SUSY models often result in signatures with
  - energetic jets
    - squark/gluino decays
  - missing transverse energy (MET)
    - transverse energy imbalance from lightest neutralino escaping the detector
  - possibly leptons
- 3rd generation squarks may be much lighter due to large mixing
  - stop/sbottom
- Production mechanisms
  - direct pair production
  - gluino decays



Gluino/squark production have larger cross sections, but also sensitive to direct production of 3rd generation

# Search Strategies

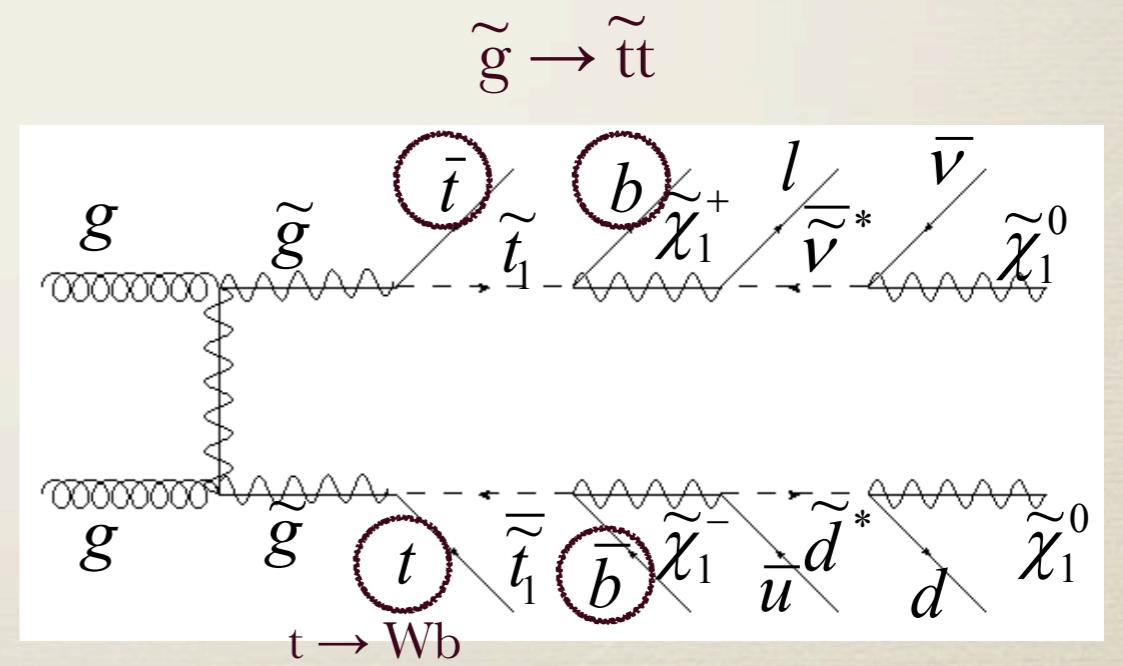
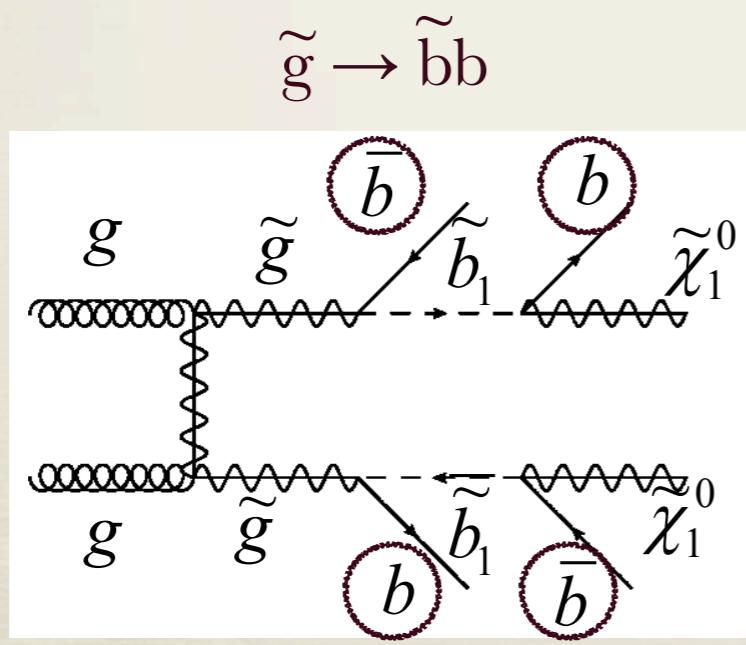
- Initial searches focus on production through gluino decays
- Stop/sbottom decays involve b-quarks -- specifically identify these

- ATLAS searches

- 0-lepton,  $\geq 3$  jets with  $\geq 1/2$  b-jets
  - sbottom-targeted search
- 1-lepton,  $\geq 4$  jets with  $\geq 1$  b-jets
  - stop-targeted search

← **ATLAS-CONF-2011-098 (0.83 fb<sup>-1</sup>)**

← **ATLAS-CONF-2011-130 (1.03 fb<sup>-1</sup>)**



# Object Selection

**electron:** ID track + calorimeter cluster

- $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.47$
- tight electron identification cuts
- separated from jets by  $dR > 0.4$

**muon:** ID track + hits in muon system

- $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.4$
- isolated from other nearby tracks
- separated from jets by  $dR > 0.4$

**jets:**

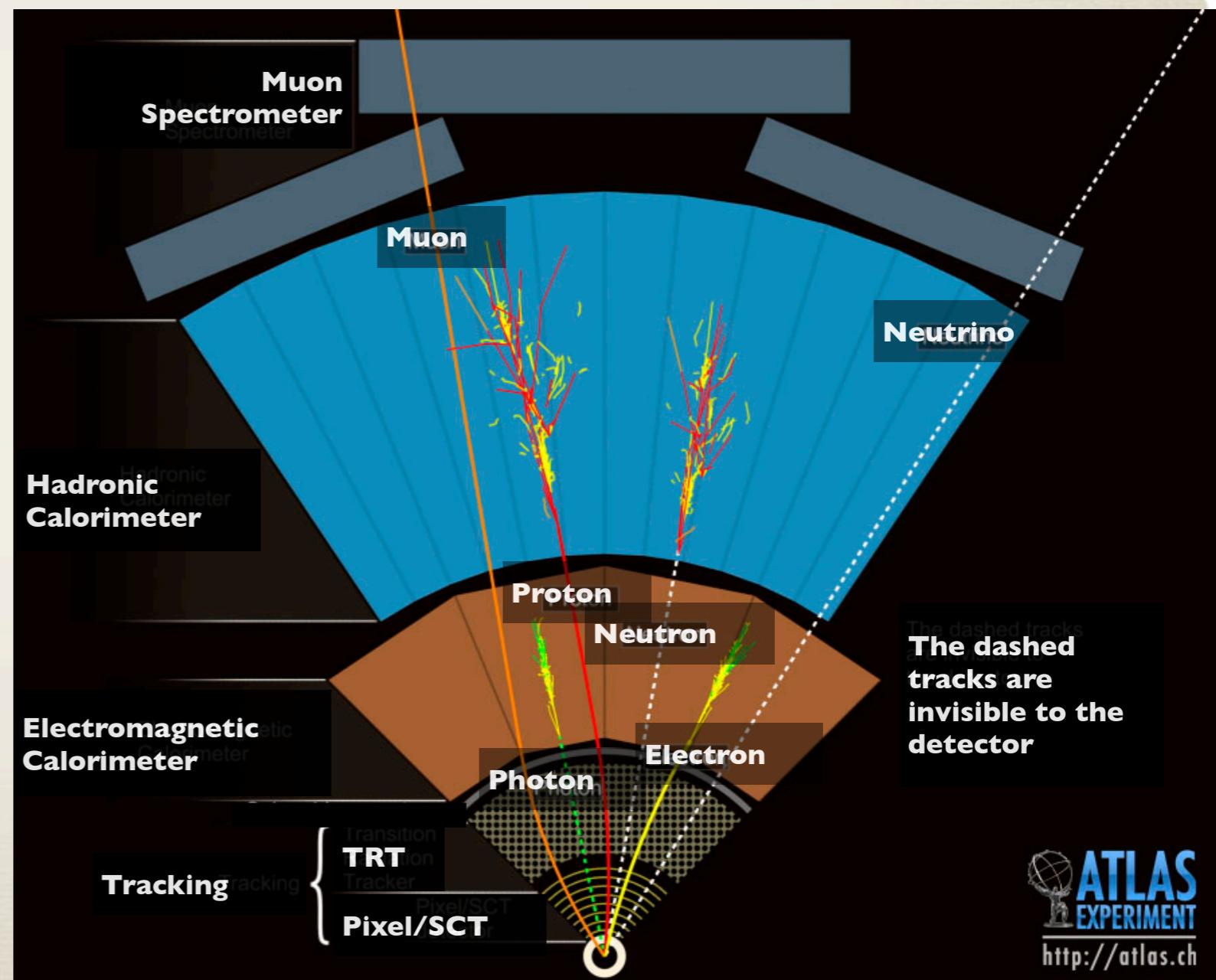
- reconstructed with anti- $k_T$  jet clustering algorithm
- $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.8$ 
  - higher analysis  $p_T$  cuts

**b-jets:**

- $p_T > 50 \text{ GeV}$
- “b-tagged”
- **next slide!**

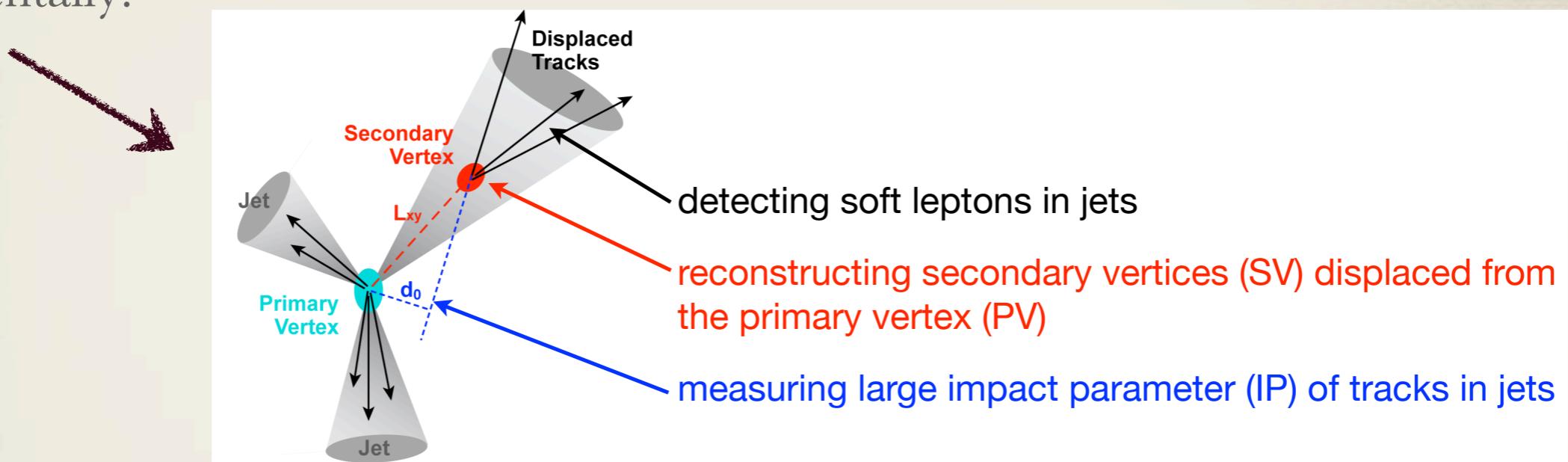
**missing  $E_T$ :**

- calculated from vector sum of reconstructed jets ( $p_T > 20 \text{ GeV}$ ,  $|\eta| < 4.5$ ), leptons & unmatched calorimeter clusters



# Identifying b-jets

- Why are jets hadronizing from b-quark different than light quark jets?
  - Properties of b-hadrons
    - High mass & many decay particles
    - Long lifetime: b-hadron in 50 GeV jet flies  $\sim$ 3mm before decaying
    - Semi-leptonic decays
  - Experimentally?



- Taggers used for these analyses
  - Sbottom search:
    - SV-tagger with 50% (1%) efficiency for b-jets (light/gluon jets)
  - Stop search:
    - IP & SV information with 60% (1%) efficiency for b-jets (light/gluon jets)



b-taggers: tradeoff between efficiency & rejection power

# Discriminating Variables

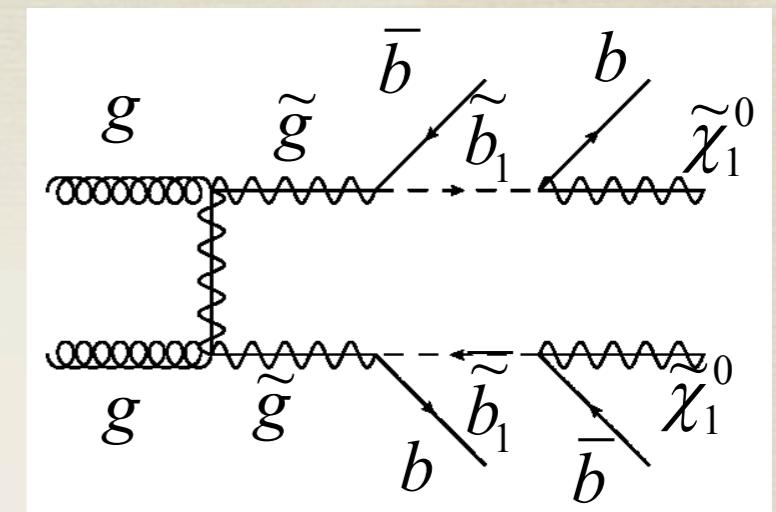
- To define signal regions, different discriminating variables are used:
  - **$m_{\text{eff}}$**  -- scalar sum of ...
    - 0-lepton ... MET & 3 leading jet  $p_T$
    - 1-lepton ... MET & 4 leading jet  $p_T$  & identified lepton  $p_T$
  - **$m_T$**  -- missing transverse mass
    - calculated from MET & lepton
  - **$\Delta\phi_{\min}$** 
    - minimum azimuthal distance between any of 3 leading jets & MET
    - ... cut to reduce QCD multijet background from misreconstructed MET



$$m_T = \sqrt{2(p_T^{\text{lepton}} E_T^{\text{miss}} - \vec{p}_T^{\text{lepton}} \cdot \vec{E}_T^{\text{miss}})}$$

# 0-lepton Search

- Gluino-mediated sbottom production
- Event selection
  - **0-lepton**
    - veto events with  $e/\mu$  with  $p_T > 20/10$  GeV
  - **$\geq 3$  jets** (of which  $\geq 1/2$  b-jets)
    - $p_T > 130/50/50$  GeV
  - **MET**  $> 130$  GeV
  - Additional requirements to reduce QCD multijet background
    - $\text{MET}/m_{\text{eff}} > 0.25$
    - $\Delta\phi_{\min} > 0.4$
- Signal regions
  - **3JA**  $\geq 1$  b-jet,  $m_{\text{eff}} > 500$  GeV
  - **3JB**  $\geq 1$  b-jet,  $m_{\text{eff}} > 700$  GeV
  - **3JC**  $\geq 2$  b-jet,  $m_{\text{eff}} > 500$  GeV
  - **3JD**  $\geq 2$  b-jet,  $m_{\text{eff}} > 700$  GeV



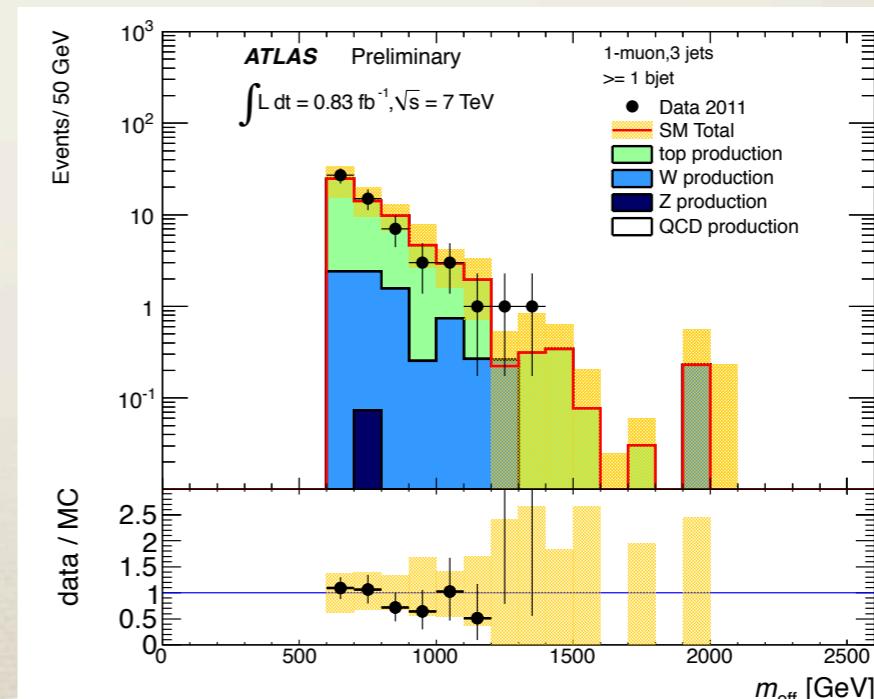
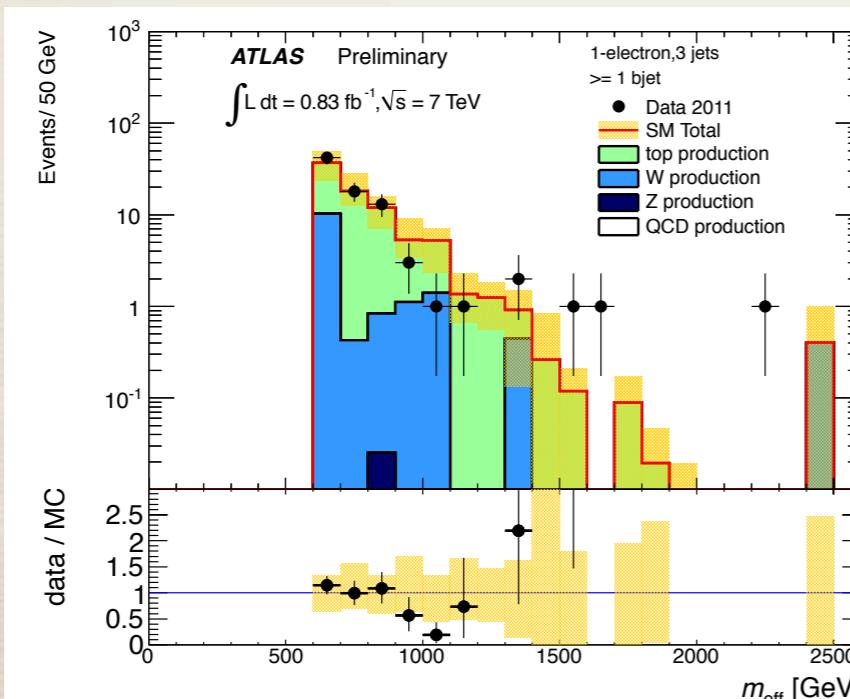
← Driven by jet/MET trigger requirement →

# 0-lepton

# Background Estimate (1)

- Standard Model backgrounds
    - top pair production
      - dominant in all signal regions!
    - W/Z+jets
    - single top production
    - QCD multijet
- } Estimated from MC
- } Data-driven estimate
- Cross check MC estimate of **top background** in control sample with 1-lepton
    - $e/\mu$  with  $p_T > 20 \text{ GeV}$
    - $m_{\text{eff}} > 600 \text{ GeV}$
    - $40 \text{ GeV} < m_T < 100 \text{ GeV}$

**Electron channel**

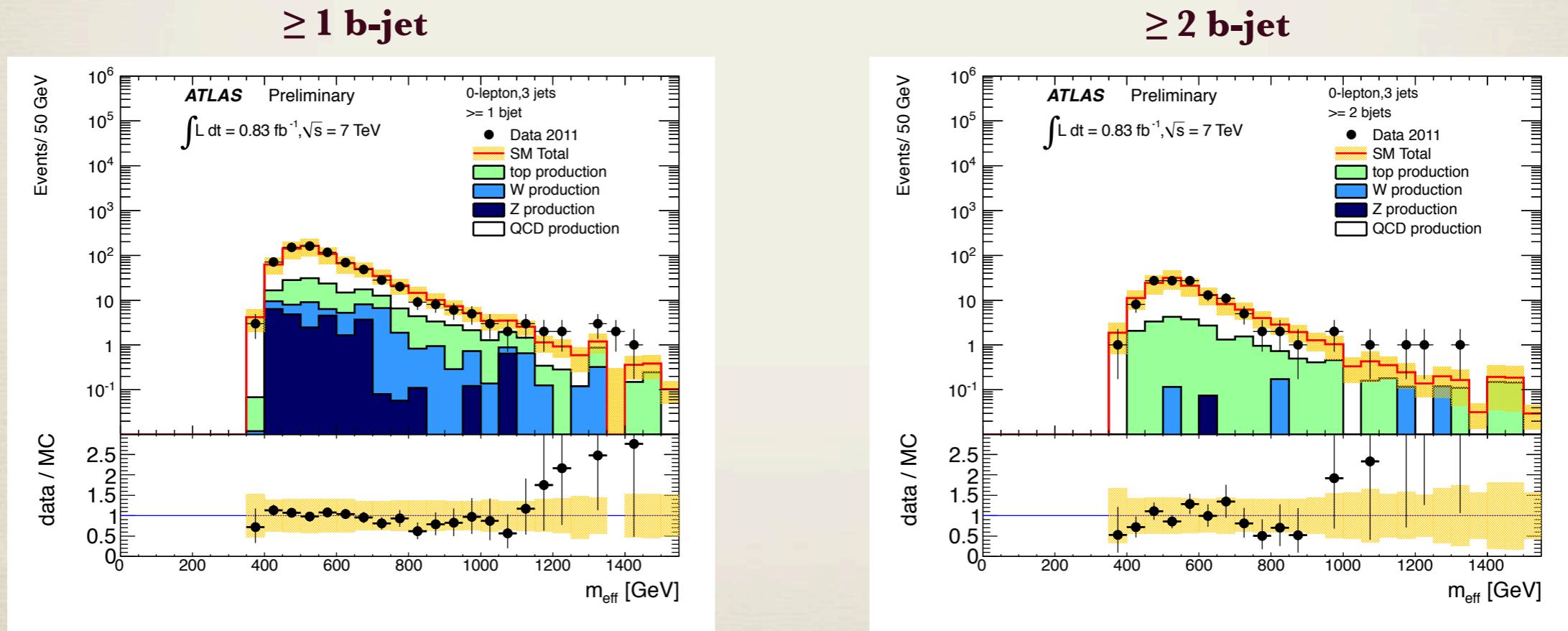


**Muon channel**

# 0-lepton

# Background Estimate (2)

- QCD multijet background estimated from data
- Relies on assumption that MET in these events is due to mismeasured jets
  - Smear jet pt in low-MET events to create “pseudoevents” with large fake MET
  - Validate by comparing distributions in QCD control region with  $\Delta\phi_{\text{min}} < 0.4$
- Below  $m_{\text{eff}}$ , showing good agreement between data & pseudoevents



- Systematic uncertainties
  - Dominant
    - jet energy scale & resolution
    - b-tagging efficiency
    - uncertainty on theoretical cross sections & ISR/FSR for ttbar
    - SUSY cross sections
  - Additional uncertainties e.g. from QCD MET smearing, luminosity
- Resulting event yield
  - Good agreement between prediction & observation

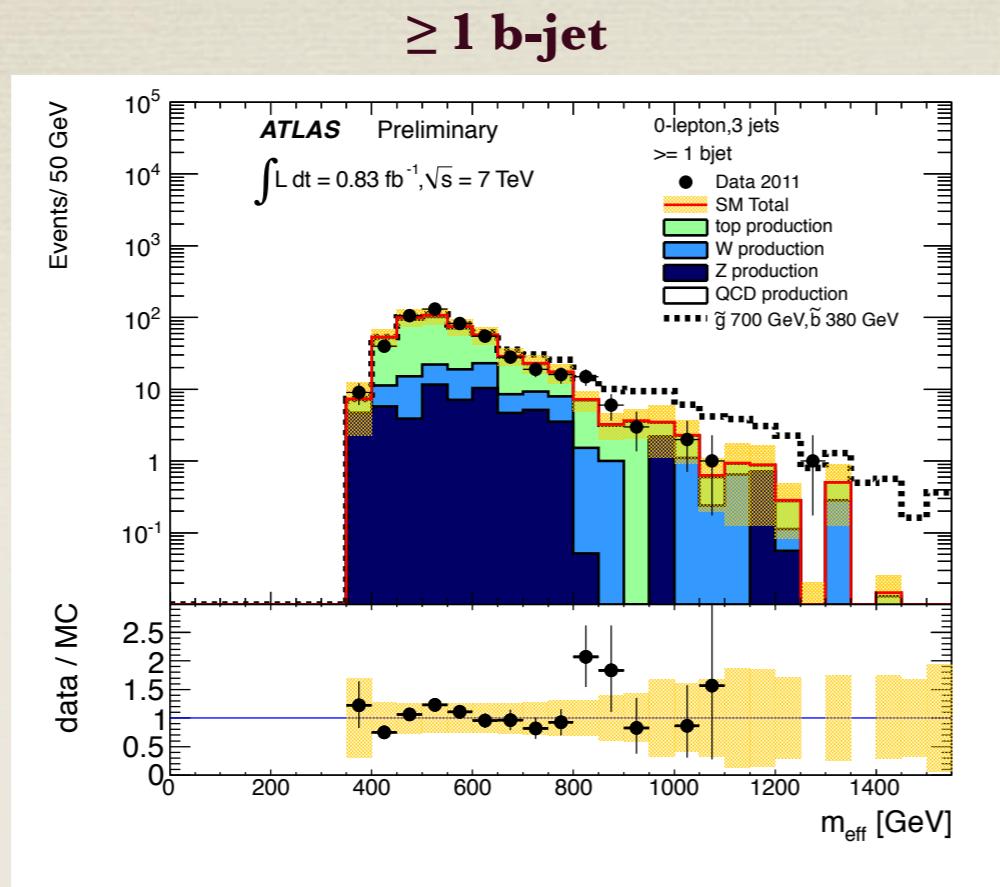
Sig. Reg.	Data ( $0.83 \text{ fb}^{-1}$ )	Top	W/Z	QCD	Total
3JA (1 btag $m_{\text{eff}} > 500 \text{ GeV}$ )	361	$221^{+82}_{-68}$	$121 \pm 61$	$15 \pm 7$	$356^{+103}_{-92}$
3JB (1 btag $m_{\text{eff}} > 700 \text{ GeV}$ )	63	$37^{+15}_{-12}$	$31 \pm 19$	$1.9 \pm 0.9$	$70^{+24}_{-22}$
3JC (2 btag $m_{\text{eff}} > 500 \text{ GeV}$ )	76	$55^{+25}_{-22}$	$20 \pm 12$	$3.6 \pm 1.8$	$79^{+28}_{-25}$
3JD (2 btag $m_{\text{eff}} > 700 \text{ GeV}$ )	12	$7.8^{+3.5}_{-2.9}$	$5 \pm 4$	$0.5 \pm 0.3$	$13.0^{+5.6}_{-5.2}$

# 0-lepton

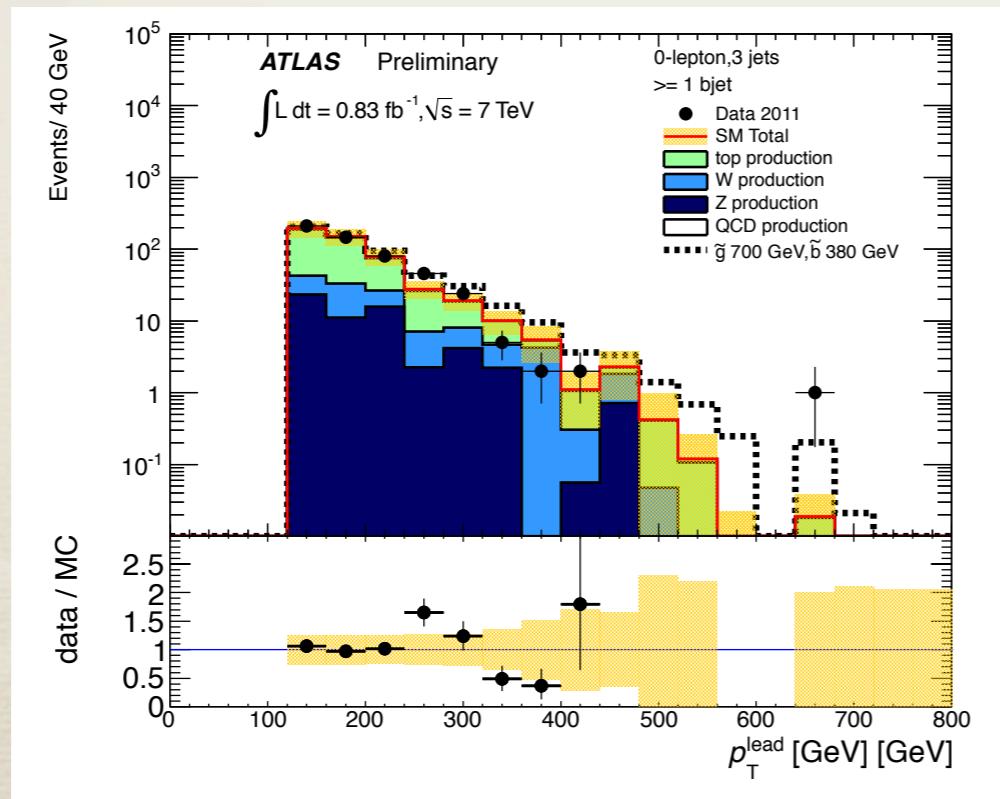
# Results

SUSY signal with  $m(\text{gluino}) = 700 \text{ GeV}$ ,  
 $m(\text{sbottom}) = 380 \text{ GeV}$

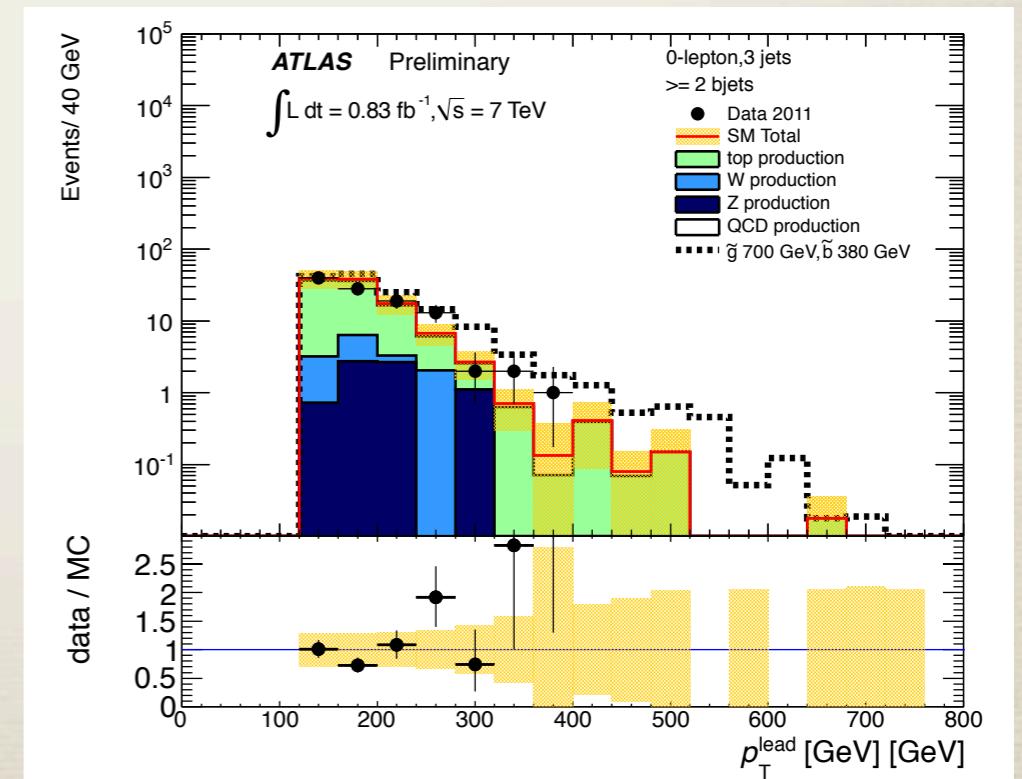
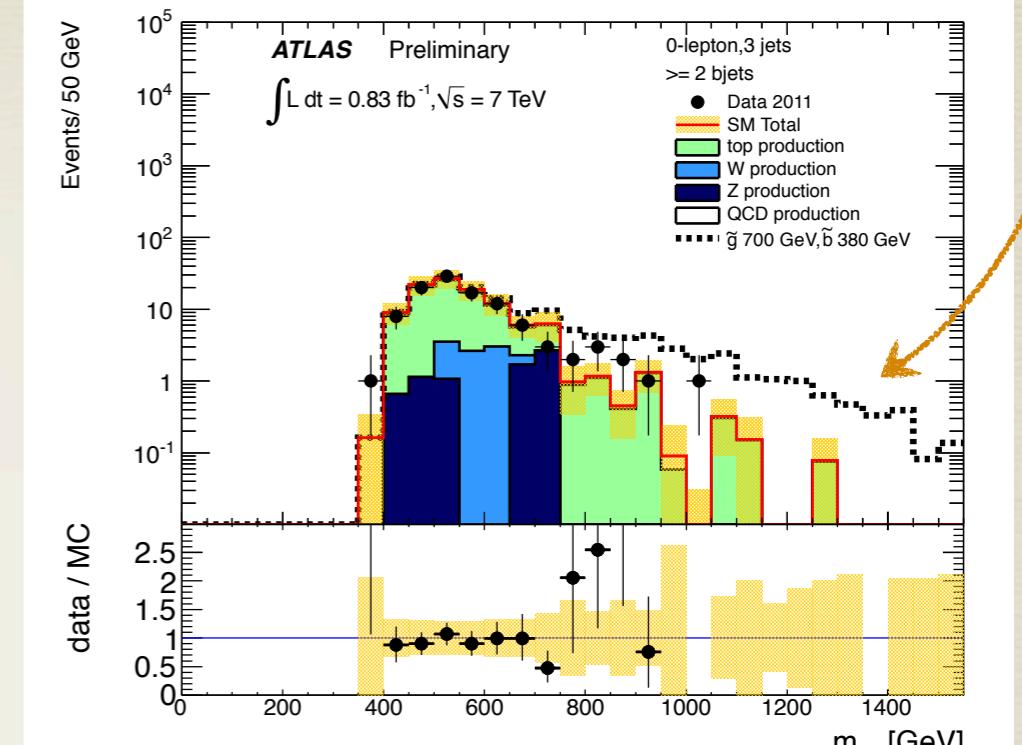
**effective mass**



**leading jet  $p_T$**



**$\geq 2 \text{ b-jet}$**

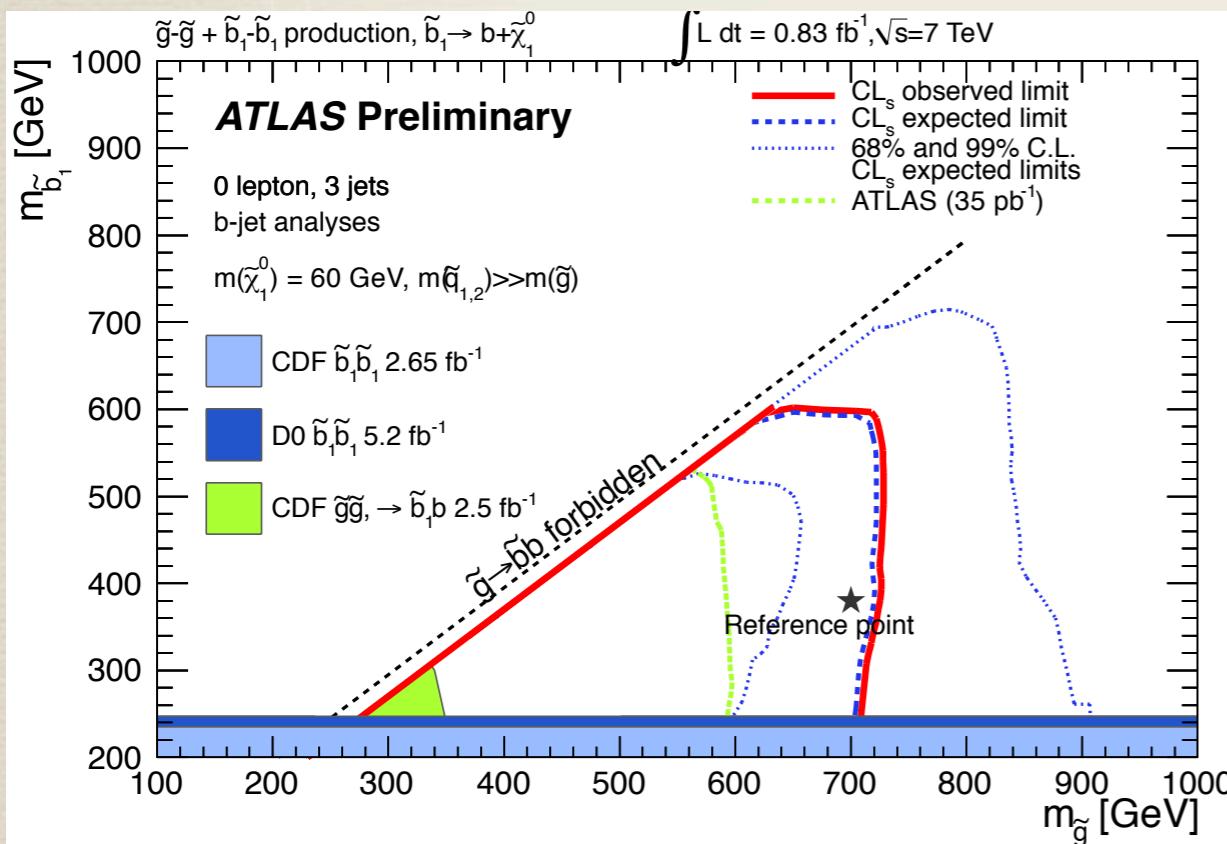


# 0-lepton

# Interpretation & Limits

## **m(sbottom) vs m(gluino)**

gluino masses < 720 GeV excluded for  
sbottom masses to 600 GeV

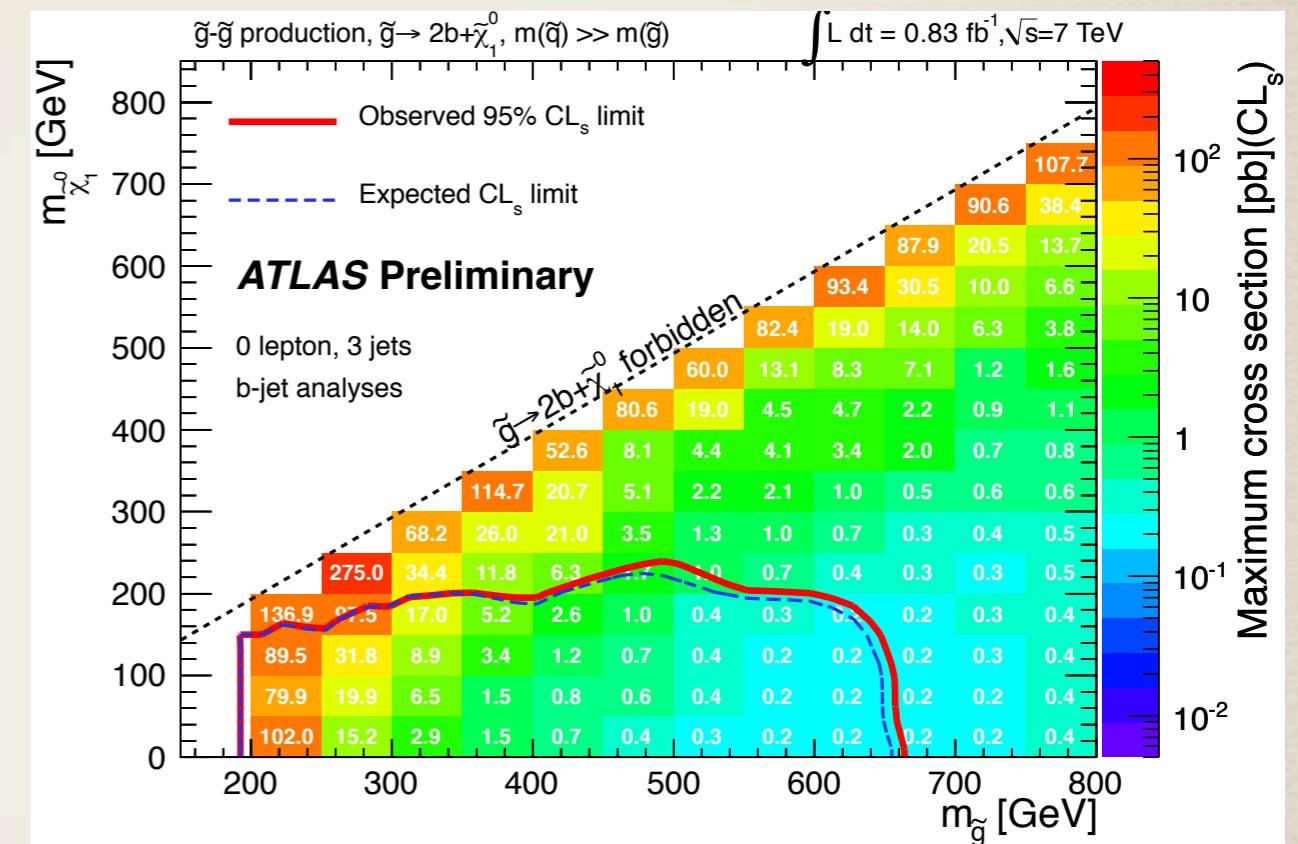


$m(\text{neutralino}) = 60 \text{ GeV}$

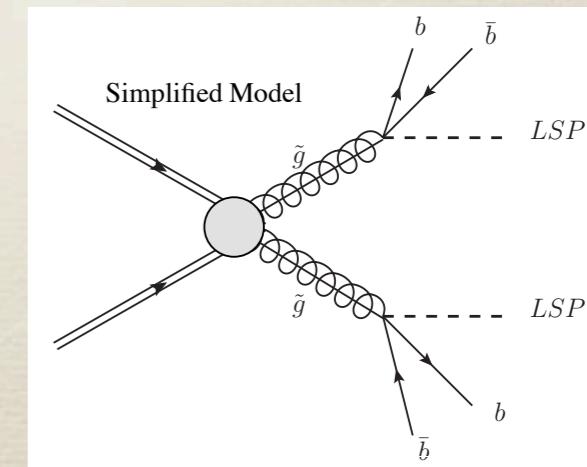
Signal region with best expected exclusion limit used  
for each mass point

## **Simplified model**

LSP masses < 200-250 GeV excluded for  
 $m(\text{gluino}) < 660 \text{ GeV}$ , assuming mass  
splitting > 100 GeV



Simplified model with all squarks heavier than gluino, 3-body decay to b-quarks & neutralino



# 1-lepton Search

- Gluino-mediated stop production
- Event selection
  - **== 1 lepton**
    - e/ $\mu$  with  $p_T > 25/20$  GeV
  - **$\geq 4$  jets** (of which  $\geq 1$  b-jet)
    - $p_T > 50$  GeV
  - **MET**  $> 80$  GeV
- Signal region
  - $m_T \geq 100$  GeV &  $m_{\text{eff}} > 600$  GeV
- Backgrounds
  - ttbar, W/Z+jets, single top
    - semi data-driven estimate
  - QCD multijet
    - small, estimate from data

**Stop decays:**

stop  $\rightarrow$  top+neutralino  
stop  $\rightarrow$  bottom+chargino

Now trigger on lepton instead of jet/MET



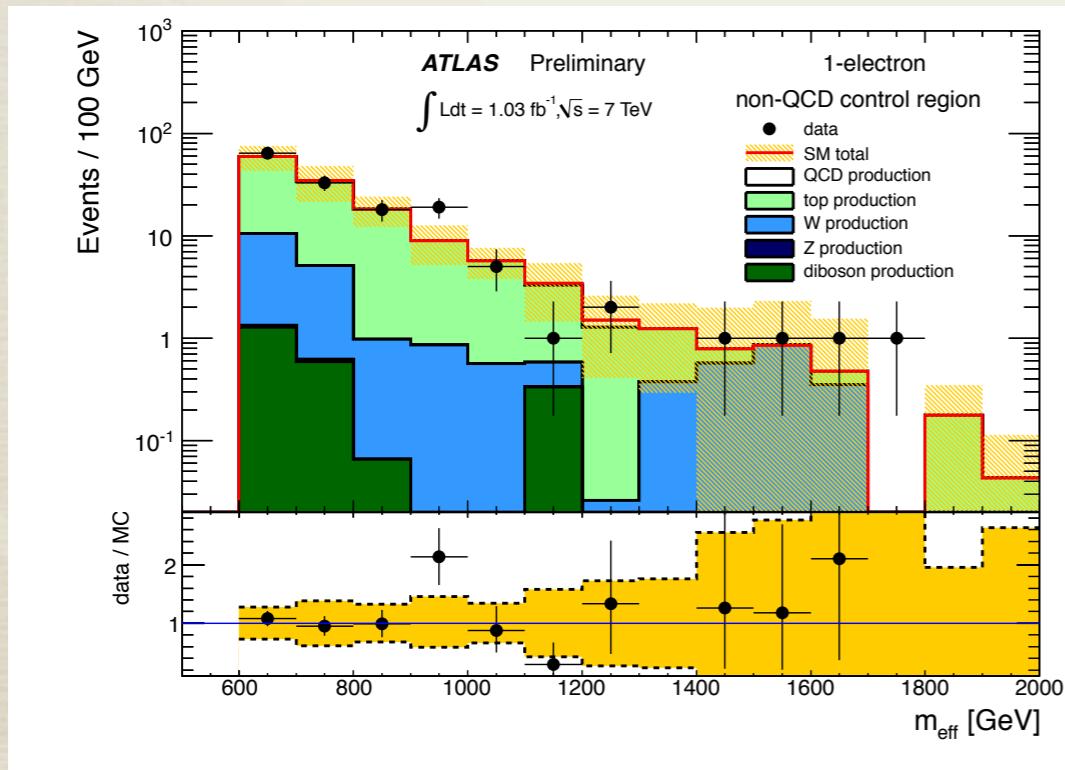
# 1-lepton

# Background Estimate

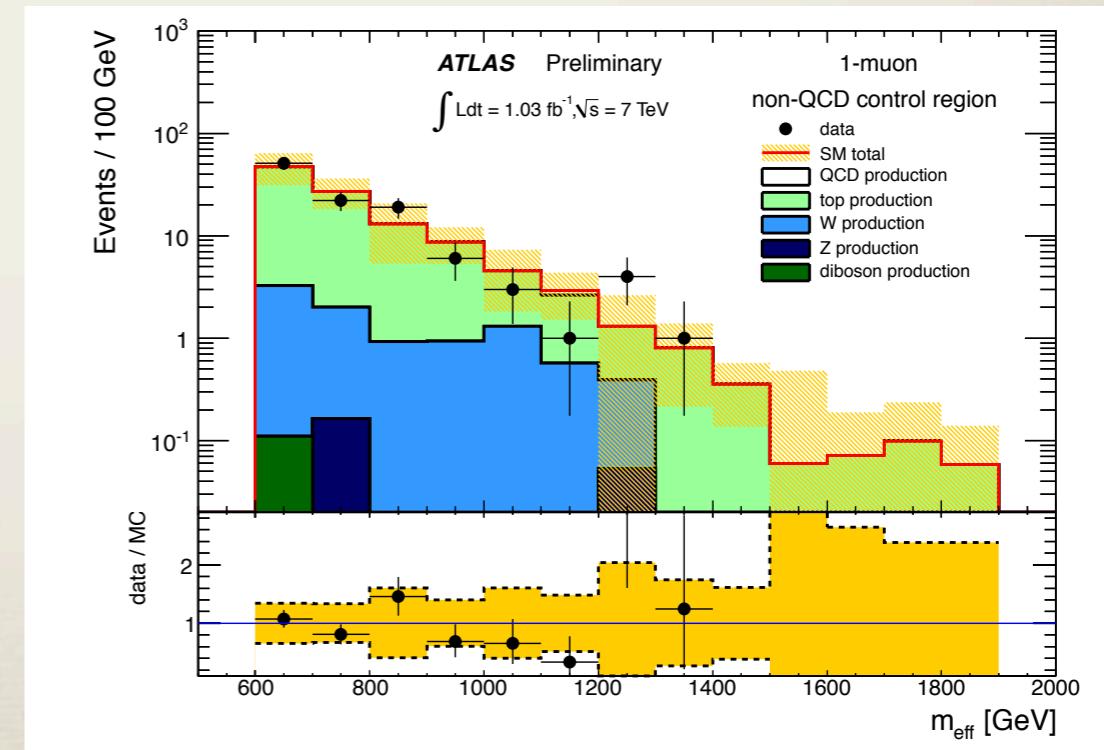
- QCD background small
  - Estimate through a “matrix method”, translating loose & tight leptons to real & fake
- ttbar, W/Z+jets, single top
  - Use MC to propagate measured number of background events in a control region to the signal region
    - Use control region (CR) with modified  $m_T$  requirement,  $40 \text{ GeV} < m_T < 100 \text{ GeV}$
    - Signal region (SR) estimate determined as:
  - Good agreement

$$N_{\text{data}}^{\text{SR}} = N_{\text{data}}^{\text{CR}} \frac{N_{\text{MC}}^{\text{SR}}}{N_{\text{MC}}^{\text{CR}}}$$

**effective mass for electron CR**



**effective mass for muon CR**



- Systematic uncertainties
  - statistical uncertainty in CR used for non-QCD background
  - ttbar theory uncertainties
  - theory uncertainties on signal cross section
    - Smaller uncertainties from jet energy scale, b-tagging efficiency, ...
- Resulting event yield
  - Agreement between prediction & observation within errors
    - 1.2sigma upward fluctuation (similar in e/ $\mu$  channels)

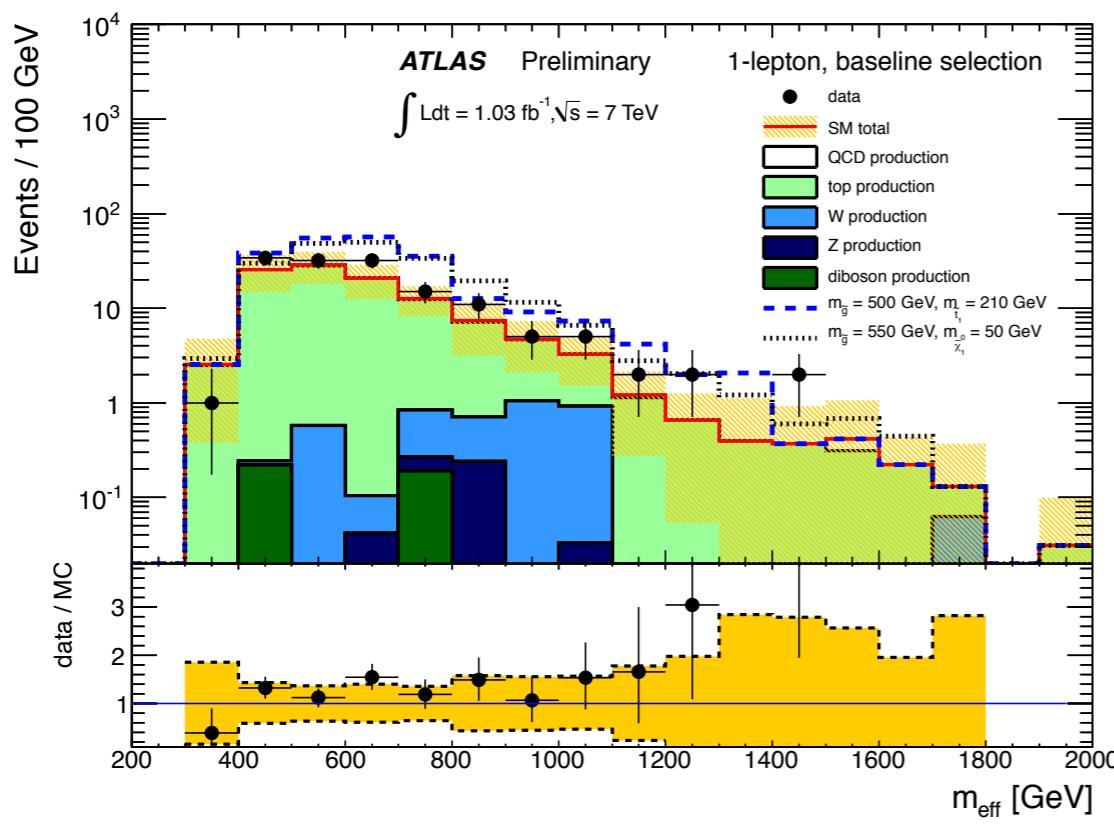
**expected & observed event yields (e/ $\mu$  combined)**

Cuts	$\geq 4$ jets	$\geq 1$ b jet	$E_T^{\text{miss}} > 80$ GeV	$m_T > 100$ GeV	$m_{\text{eff}} > 600$ GeV
top	$3360 \pm 1250$	$2590 \pm 970$	$810 \pm 337$	$103 \pm 53$	$48 \pm 27$
$W + \text{jets}$	$1850 \pm 750$	$210 \pm 130$	$55 \pm 36$	$3.7 \pm 3.1$	$3.1 \pm 2.9$
$Z + \text{jets}$	$410 \pm 170$	$39 \pm 24$	$2.4 \pm 3.1$	$0.4 \pm 0.4$	$0.4 \pm 0.3$
diboson	$87 \pm 36$	$10 \pm 6$	$4.0 \pm 2.5$	$0.4 \pm 0.4$	$0.2 \pm 0.2$
QCD (d-d)	$870 \pm 270$	$247 \pm 121$	$9.7 \pm 16.8$	$1.1 \pm 2.3$	$0.9 \pm 1.2$
SM (MC)	$6574 \pm 1870$	$3096 \pm 1042$	$881 \pm 356$	$109 \pm 55$	$52 \pm 28$
SM (d-d)					$54.9 \pm 13.6$
data	6659	3361	989	141	74

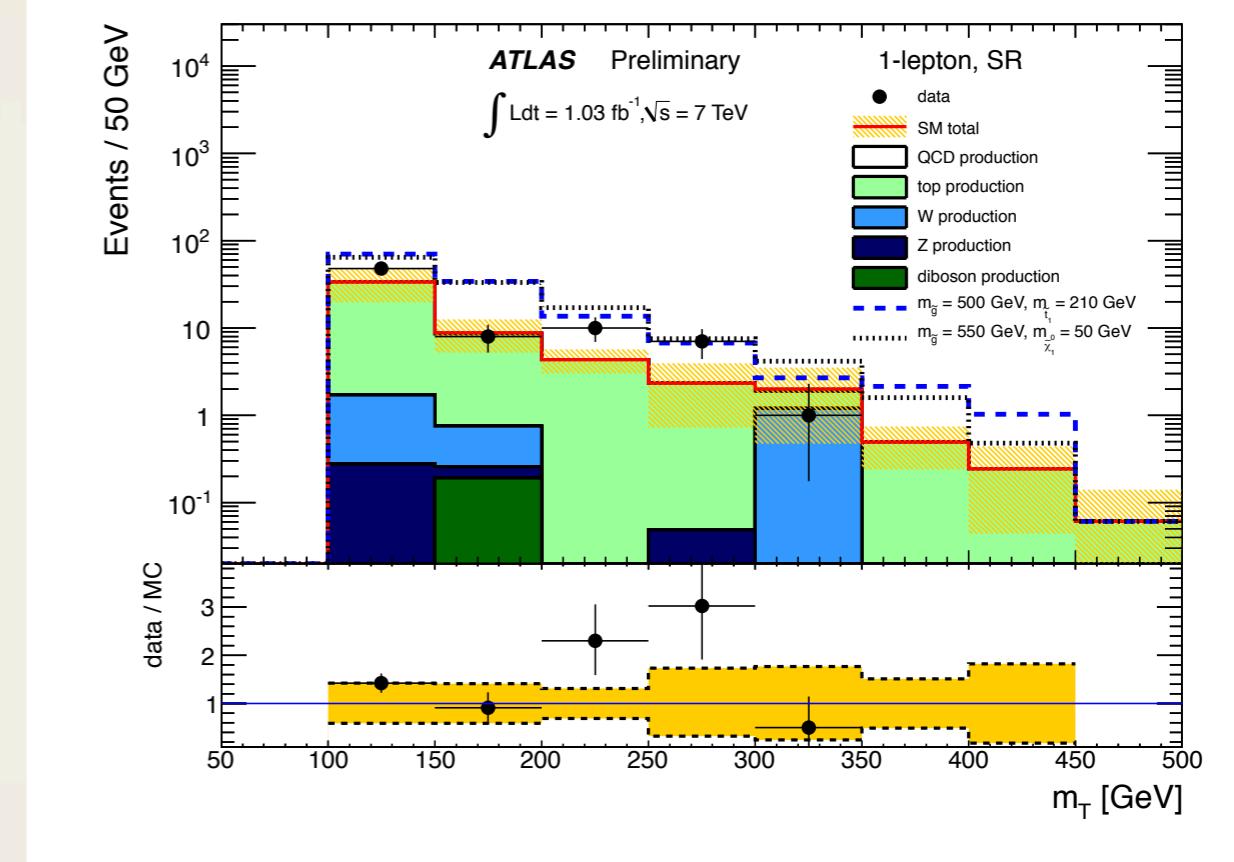
# 1-lepton

# Results

**effective mass, signal region  
BEFORE  $m_{\text{eff}}$  cut**



**transverse mass, signal region  
AFTER  $m_{\text{eff}}$  cut**

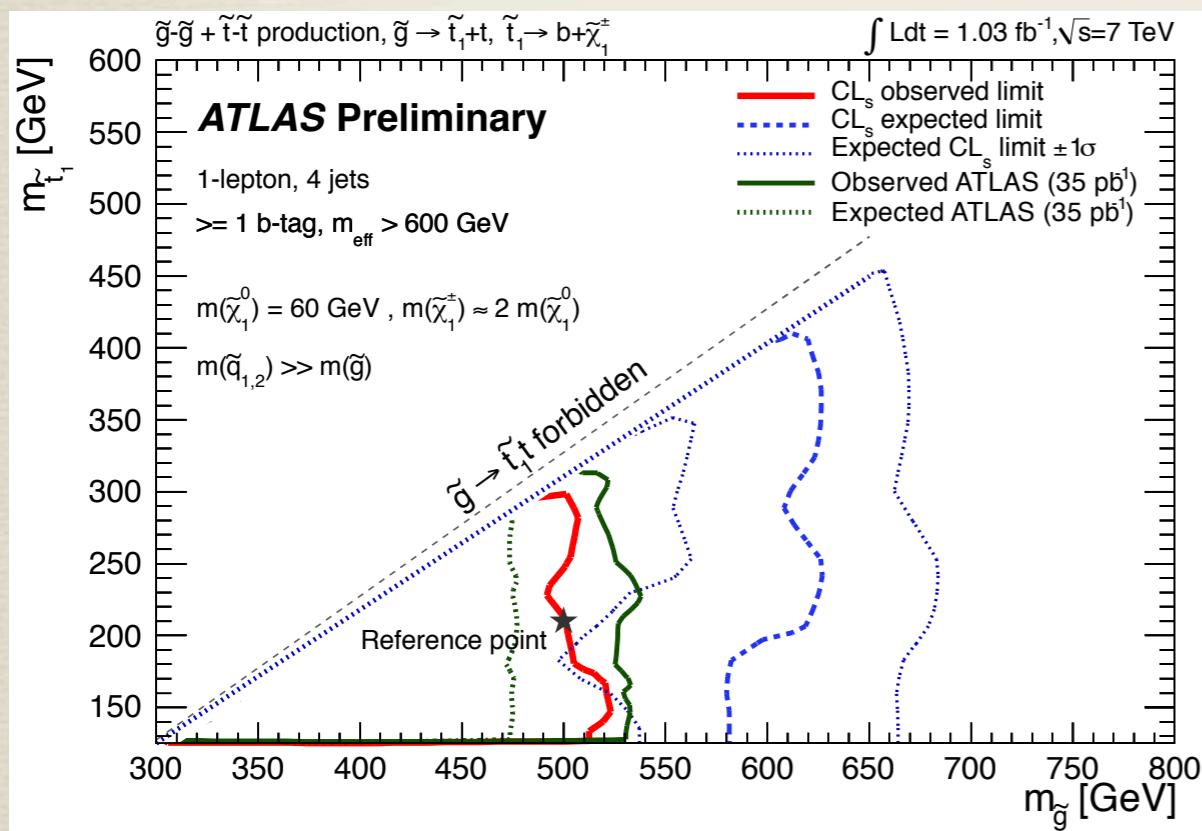


# 1-lepton

# Interpretation & Limits

## **m(stop) vs m(gluino)**

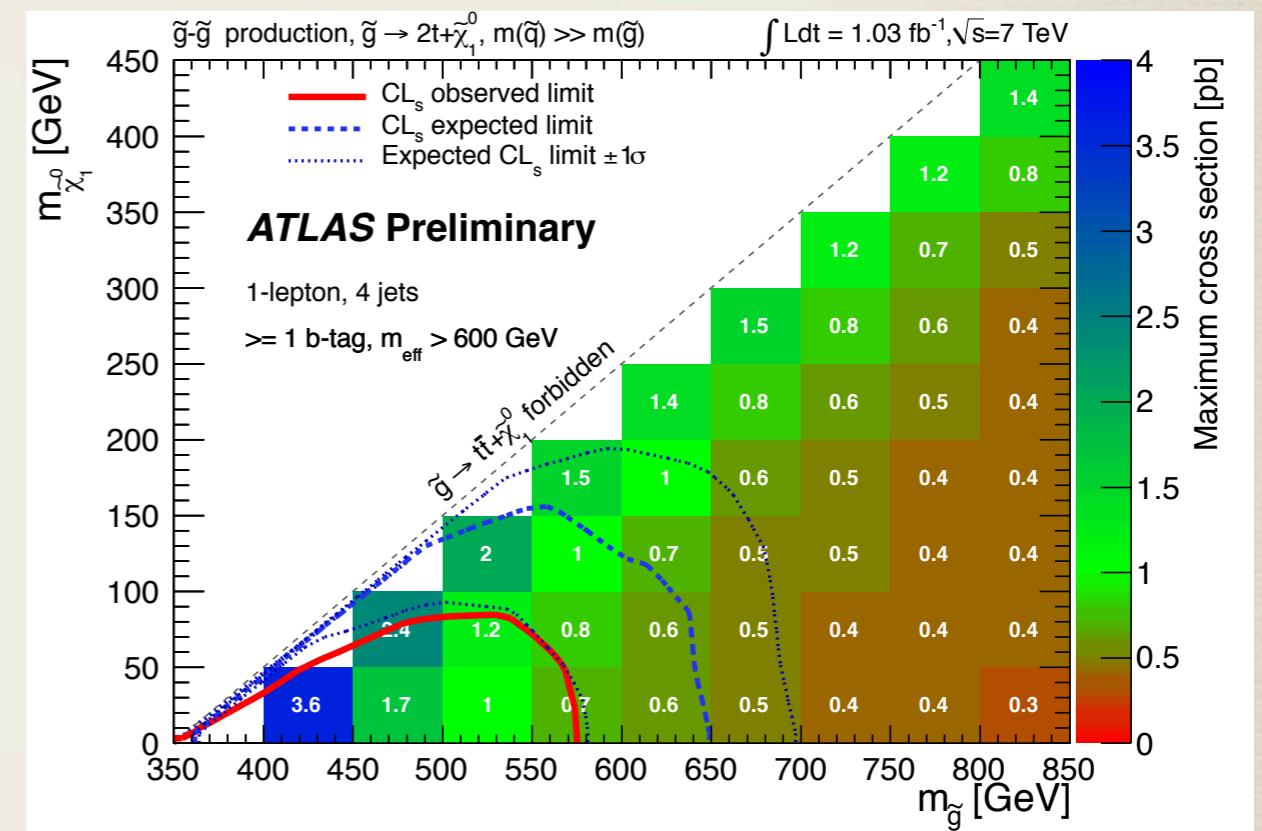
gluino masses < 500 GeV excluded for stop masses between 125-300 GeV



$m(\text{neutralino}) = 60$  GeV

## **Simplified model**

gluino masses < 570 GeV excluded for  $m(\text{LSP}) < 40$  GeV



# Conclusions

- Searches for gluino-mediated stop/sbottom performed using  $0.83/1.03 \text{ fb}^{-1}$ 
  - sbottom: 0-lepton, jets & b-jets, MET
    - gluino masses  $< 720 \text{ GeV}$  excluded for sbottom masses up to  $600 \text{ GeV}$
  - stop: 1-lepton, jets & b-jets, MET
    - gluino masses  $< 500 \text{ GeV}$  excluded for stop masses between  $125\text{-}300 \text{ GeV}$
- Analyses of the full 2011 dataset ongoing
  - put limits on direct production of 3rd generation
  - constrain parts of parameter space not addresses by these searches
    - these e.g. assume large MET (compare e.g. Michele's talk on Oct 12)